Spectra of particles produced in high-mass diffraction dissociation in the Model of Quark-Gluon Strings

A.B. Kaidalov[1] and M.G. Poghosyan[2]

[1]Institute of Theoretical and Experimental Physics, 117259 Moscow, Russia

[2]Universitá di Torino/INFN, 10125 Torino, Italy

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Abstract

We calculate spectra of secondary particles produced in process of single diffraction dissociation in the Model of Quark-Gluon Strings. For description of diffractive dissociation process we use the reggeon model where all legs of triple-reggeon diagrams are eikonalized. Numerical calculation shows that the model gives a good description of data on charged particles pseudorapidity distribution in $p\bar{p}$ single diffractive dissociation.

1 Introduction

The role of hardonic soft interactions is hard to over-estimate, since they are responsible for multi-particle production in high-energy hadronic collisions. Low-momentum transfer characterizes these processes and the strong interaction constant is not a small parameter for them. As a consequence pQCD cannot be used for their study. The models of Quark-Gluon Strings (QGSM) [1] and Dual-Parton Model (DPM) [2], are based on nonperturbative notions, combining $1/N$ expansion in QCD with Regge theory and using parton structure of hadrons. In both approaches the matrix element of hadron-hadron scattering amplitude consists from planar diagrams (related to flavor exchange), which are associated with secondary-Reggeon exchange diagrams in Reggeon Field Theory (RFT) and cylinder-type diagrams (related to color exchange), which are associated with Pomeron exchange in RFT.

$1/N$ expansion is a dynamical expansion and the speed of convergence depends on the kinematical region of studying process. At very high energies many terms of the expansion (multi-pomeron exchanges) should be taken into account.

In ref. [3] a model has been developed, where all possible eikonal-type corrections are taken into account in triple-reggeon diagrams. It was applied for discription of soft single-diffractive dissociation process in hadronic interactions. It was shown that it is possible to describe data on diffractive pp and $p\bar{p}$ differential cross-sections in a wide energy range (from $P_{lab} = 65$ GeV/c to $\sqrt{s} = 1800$ GeV) accessible by different accelerators of CERN and Fermilab. In this article we incorporate QGSM into the model and give description of data on spectra of secondary particles produced in single diffraction dissociation.

2 Single-diffraction dissociation cross-section

It was proposed in Ref. [3] to describe soft single-diffractive process in the model where any number pomeron exchanges is taken into account together with each reggeon (pomeron or secondary-reggeon, which was considered as f-trajectory) of the triple-reggeon diagrams. The screening corrections between initial and final hadrons were also taken into account in the eikonal approximation, as shown in Fig. 1. This approach allowed to describe inclusive spectra in single diffractive pp and $p\bar{p}$ interactions from FNAL, ISR to Tevatron energies. For multi-reggeon interaction vertices eikonal-type
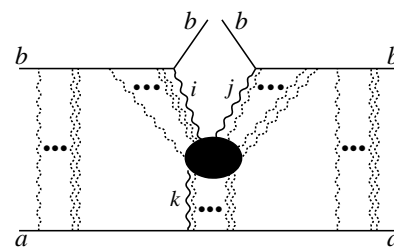

Figure 1: Eikonalized triple-reggeon diagram that is proposed in Ref. [3] to describe single-diffractive dissociation process, $b + a \rightarrow b + X$, in hadron-hadron collisions.

structure was assumed, as shown in Fig. 2, which allowed to calculate and to sum the matrix elements. In this approach the system of hadrons, produced in diffraction dissociation of a hadron can be considered as a non-diffractive interaction of a hadron with the $q\bar{q}$ system which is responsible for inelastic interaction of reggeons or pomerons. The cross-section corresponding to the di-
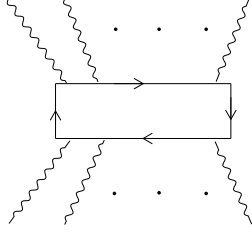
Figure 2: Eikonal-type structure assumed for multi-reggeon interaction vertices.

agram shown in Fig. 1 was calculated using Gribov's reggeon calculus and has the following form:

$$\frac{d\sigma}{d\zeta} = \frac{1}{2} \sum_{i,j,k=P,f} G_{ijk} \int d\mathbf{b}d\mathbf{b_1} \Gamma^i(\zeta_2, \mathbf{b_2})\Gamma^j(\zeta_2, \mathbf{b_2})$$

$$\times \Gamma^k(\zeta, \mathbf{b_1}) \exp\{-2\Omega_1(\xi, \mathbf{b})\} \quad (1)$$

Where the following notations are introduced:

$$\Gamma^f(\zeta, \mathbf{b}) = \frac{g_0^f}{\lambda_0^f} \exp\left\{(\alpha_f - 1)\zeta - \frac{\mathbf{b}^2}{4\lambda_0^f} - \Omega_0(\zeta, \mathbf{b})\right\},$$

$$\Gamma^P(\zeta, \mathbf{b}) = 1 - e^{-\Omega_0(\zeta, \mathbf{b})}, \ \lambda_i^k = R_i^{k2} + \alpha_k'\zeta,$$

$$\Omega_i(\zeta, \mathbf{b}) = \frac{g_i^P}{\lambda_i^P} \exp\left\{\Delta\zeta - \frac{\mathbf{b}^2}{4\lambda_i^P}\right\}, \ \xi = ln(s/s_0),$$

$$\zeta = ln(M_X^2/s_0), \ \zeta_2 = \xi - \zeta, \ \mathbf{b_2} = \mathbf{b} - \mathbf{b_1}.$$

The values of parameters are found from fit to elastic and inelastic diffractive data and have the following values: $\alpha_f = 0.7$, $\alpha_f' = 0.8$ GeV^{-2}, $\Delta = 0.117$, $\alpha_P' = 0.25$ GeV^{-2}, $g_0^P = 1.16$ GeV^{-2}, $g_1^P = 1.87$ GeV^{-2}, $g_0^f = 8.2$ GeV^{-2}, $g_1^f = 3.5$ GeV^{-2}, $R_0^{P2} = 1.9$ GeV^{-2}, $R_1^{P2} = 2.8$ GeV^{-2}, $R_0^{f2} = 1$ GeV^{-2}, $R_1^{f2} = 1.8$ GeV^{-2}, $G_{PPP} = 0.0098$ GeV^{-2}, $G_{PPR} = 0.03$ GeV^{-2}, $G_{RRP} = 0.005$ GeV^{-2}, $G_{RRR} = 0.05$ GeV^{-2}, $G_{PRP} = 0.013$ GeV^{-2}, $G_{PRR} = 0.033$ GeV^{-2}. s_0 is a constant scale factor, chosen to be $s_0 = 1$ GeV^2.

Spectra of particles produced in single-diffractive dissociation we calculate within the framework of QGSM. In the next section we give brief description of the model.

3 QGSM

In QGSM the production of a particle is defined through production of showers and each shower corresponds to the cut-pomeron pole contribution in the elastic scattering amplitude. The association of the pomeron with cylinder-type diagrams leads to the fact that in a single cut-pomeron diagram there are two chains of particles (strings). Analogously, in case of n cut-pomerons there are $2n$ chains. Inclusive distribution of particles in rapidities for non-diffractive events can be expressed in terms of rapidity distributions for $2n$-chains $f_n(\xi, y)$:

$$\frac{d\sigma(\xi)}{dy} = \sum_n \sigma_n(\xi)f_n(\xi, y). \quad (2)$$

Here $\sigma_n(\xi)$ is the cross-section of producing $2n$-chains and $\xi = \ln(s/s_0)$.

Being interested in the spectra of particles produced in single diffractive process we calculate σ_n for single-diffraction dissociation in the same way as for inelastic process in $q\bar{q} - p$ interaction with $s = M^2$ or $\xi = \zeta$. For eikonal approximation, which we use the expression for σ_n are well known [1].

Spectra of secondary particles in single-diffractive dissociation process integrated over M^2 are given by the following expression:

$$\frac{d\sigma}{dy} = \sum_n \int d\zeta \frac{d\sigma_n}{d\zeta} f_n(\zeta, y) \quad (3)$$

In order to calculate the distribution of hadrons produced during the fragmentation of the strings one should take into account that the hadron can be produced in each of the $2n$-chains and the (di-)quarks, which stretch the strings, carry only a fraction of energy of the incoming protons. In these terms, the inclusive spectra can be written as convolution of the probabilities to find a string with certain rapidity length and the fragmentation function, which defines the distribution of hadrons in the string breaking process.

For meson-nucleon collisions the function $f_n(\xi, y)$ is written as follows [1]:

$$f_n^h(\xi, y) = a^h \left[F_{\bar{q}}^{h(n)}(x_+)F_q^{h(n)}(x_-) + F_{qq}^{h(n)}(x_+)F_q^{h(n)}(x_-) \right.$$

$$\left. +2(n-1)F_s^{h(n)}(x_+)F_{\bar{s}}^{h(n)}(x_-) \right], \quad (4)$$

where $x_\pm = (1/2)[\sqrt{x_T^2 + x^2} \pm x]$, $x_T = 2m_T^h/\sqrt{s}$ and x is the Feynman-x of produced hadron h. Here $\sqrt{s}$ is the center of mass energy of meson-nucleon system. a^h is the density of hadrons h produced at mid-rapidity in a single chain and its value is determined from experimental data. In fact these are the only free parameters in the model that are fixed from fit to data. In articles [1] and [4] the following values are found for them: $a^\pi = 0.44$, $a^K = 0.055$, $a^p = 0.07$. The first two terms in Eq. (4) correspond to the chains, which connect "valence" quarks and di-quarks, and the last term corresponds to chains connected to the sea quarks-antiquarks. The functions $F_i^{h(n)}(x)$ being a convolution of the structure $\psi(x)$, and fragmentation $G(x)$, functions have the following form for the quarks and diquark of the incoming proton:

$$F_{q_{val}}^{h(n)}(x_\pm) = \frac{2}{3} \int_{x_\pm}^1 dx \psi_{u_{val}}(n, x)G_u^h\left(\frac{x_\pm}{x}\right)$$

$$+\frac{1}{3} \int_{x_\pm}^1 dx \psi_{d_{val}}(n, x)G_d^h\left(\frac{x_\pm}{x}\right).$$

$$F_{qq}^{h(n)}(x_\pm) = \frac{2}{3} \int_{x_\pm}^1 dx \psi_{ud}(n, x)G_{ud}^h\left(\frac{x_\pm}{x}\right)$$

$$+\frac{1}{3}\int_{x_\pm}^1 dx\,\psi_{uu}(n,x)G_{uu}^h\left(\frac{x_\pm}{x}\right).$$

$$F_{q_{sea}}^{h(n)}(x_\pm)=\frac{1}{2+\delta}\left[\int_{x_\pm}^1 dx\,\psi_{u_{sea}}(n,x)G_u^h\left(\frac{x_\pm}{x}\right)\right.$$

$$+\int_{x_\pm}^1 dx\,\psi_{d_{sea}}(n,x)G_d^h\left(\frac{x_\pm}{x}\right)+$$

$$\left.\delta\int_{x_\pm}^1 dx\,\psi_{s_{sea}}(n,x)G_s^h\left(\frac{x_\pm}{x}\right)\right].$$

Where δ is the strangeness suppression parameter ($\delta \approx 1/3$). Convolution functions for quarks and anti-quarks from incoming meson can be written analogously.

In the model, the structure and fragmentation functions are determined by the corresponding Regge asymptotic behaviors in the regions $x \to 0$ and $x \to 1$ and for the full range of x an interpolation is done. The structure functions of a proton are parameterized as follows [4]:

$$\psi_{d_v}(x,n)=\psi_{d_s}(x,n)=C_d x^{-\alpha_R}(1-x)^{\alpha_R-2\alpha_B+n}$$
$$\psi_{u_v}(x,n)=\psi_{d_s}(x,n)=C_u x^{-\alpha_R}(1-x)^{\alpha_R-2\alpha_B+n-1}$$
$$\psi_{ud}(x,n)=C_{ud}x^{\alpha_R-2\alpha_B}(1-x)^{\alpha_R+n-1} \quad (5)$$
$$\psi_{uu}(x,n)=C_{uu}x^{\alpha_R-2\alpha_B+1}(1-x)^{\alpha_R+n-1}$$
$$\psi_s(x,n)=C_s x^{-\alpha_R}(1-x)^{2(\alpha_R-\alpha_B)-\alpha_\phi+n-1}$$

Where α_R=0.5, α_B=-0.5. For meson structure function we will use the following parameterization

$$\psi_{d_v}(x,n)=\psi_{\bar{d}_v}(x,n)=\psi_{u_v}(x,n)=\psi_{\bar{u}_v}(x,n)=$$
$$\psi_s(x,n)=C_q x^{\alpha_R}(1-x)^{\alpha_R+n-1} \quad (6)$$

In (5) and (6) C_i are determined from normalization condition:

$$\int_0^1 \psi_i(x,n)dx=1.$$

General technique of constructing fragmentation functions is presented in Ref. [5]. For instance, for fragmenting to a pion the parameterizations are (see [1] and [4]):

$$G_d^{\pi^+}(z)=G_u^{\pi^-}(z)=(1-z)^{2-3\alpha_R+\lambda}$$
$$G_u^{\pi^+}(z)=G_d^{\pi^-}(z)=(1-z)^{-\alpha_R+\lambda}$$
$$G_s^{\pi^+}(z)=G_s^{\pi^-}(z)=(1-z)^{1-\alpha_R+\lambda}$$
$$G_{ud}^{\pi^+}(z)=G_{ud}^{\pi^-}(z)=(1-z)^{\alpha_R+\lambda-2\alpha_R}(1-z+z^2/2)$$
$$G_{uu}^{\pi^+}(z)=(1-z)^{\alpha_R+\lambda-2\alpha_B}$$
$$G_{uu}^{\pi^-}(z)=(1-z)^{\alpha_R+\lambda-2\alpha_B+1}$$

We do not list fragmentation functions for kaons and (anti-)protons, they are taken from Ref. [4].

4 Numerical results

There are not much data on spectra of secondary particles produced in soft diffraction processes. Only available data are on charged particles pseudorapidity distribution in single-diffractive dissociation process. QGSM has been used successfully to describe data on secondary hadron inclusive cross-section integrated over transverse momentum, such as rapidity and multiplicity distribution, ratio of particles and it explains many characteristic features of hadron-hadron soft interactions. But for calculating pseudorapidity distribution from Eq. (2) or (3) we must know mean transverse momentum of particles. For this purpose we used experimentally measured $<p_t>$ for different types of particles (here we assume that the sample of secondary charged particles consists from π^+, K^+ and protons, and their anti-particles). A successful fit to the data from ISR to Tevatron energies is achieved with the second-order polynomial function of $\ln(s)$. The result of the fit is presented below and compared with data in Fig. 3.

$$<p_t^\pi>=0.34-0.002\ln s+0.00035\ln^2 s,$$
$$<p_t^K>=0.55-0.031\ln s+0.001\ln^2 s, \quad (7)$$
$$<p_t^p>=0.65-0.045\ln s+0.0036\ln^2 s.$$

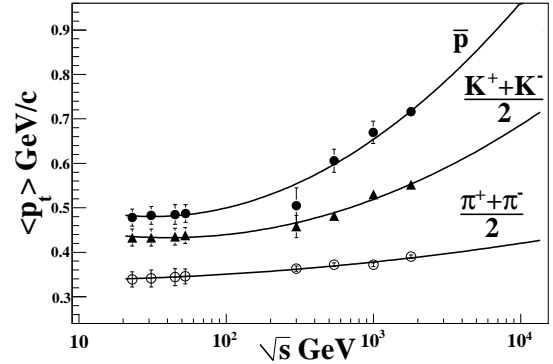In the following for each mass of the diffractive system

Figure 3: The average transverse momentum $<p_t>$ as a function of $\sqrt{s}$ for $\pi^\pm$, $K^\pm$, $\bar{p}$ [6]. The π and K data are averaged over positive and negative particles.

we calculate $<p_t>$ of each particle type using (7).

UA4 [7] provides data on charged particles pseudorapidity distribution in single-diffractive $p\bar{p}$ interaction at $\sqrt{s}=546$ GeV for six intervals of the mass for diffractively produced system. In Fig. 4 we compare the results of theoretical calculation with these data. For each mass bin the theoretical curve is calculated at mean value of the systems mass, as indicated in each graph.

UA5 [8] measured charged particles pseudorapidity distribution in $p\bar{p}$ single-diffractive interaction at three different energies ($\sqrt{s} = 200$ GeV, 546 GeV and 900 GeV), and for integrated mass spectra of the diffractive system ($M^2 \leq 0.05s$). In Fig. 5 we give description of these data.
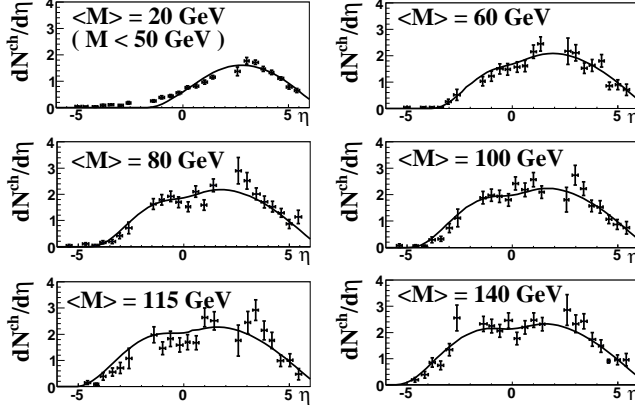

Figure 4: Description of UA4 data on charged particles pseudorapidty distribution in $p\bar{p}$ single-diffractive evens for different values of the diffractive mass.
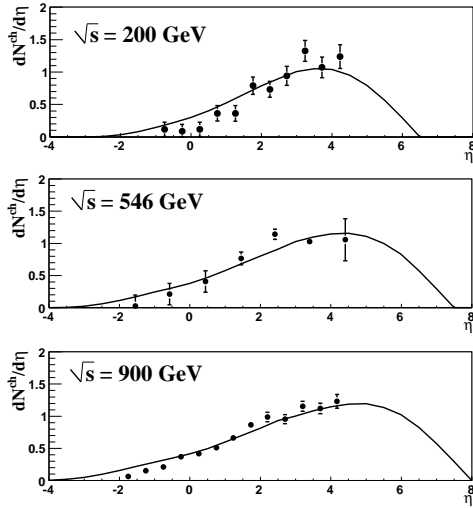

Figure 5: Description of UA5 data on charged particles pseudorapidity distribution in $p\bar{p}$ single-diffractive evetns. The indicated errors are statistical and the systematical errors are unknown.

5 Conclusion

Incorporating the model, proposed in Ref [3] for description of cross sections for single-diffractive dissociation process, with the Model of Quark-Gluon Strings, a good description of available S$p\bar{p}$S data on particles spectra in $p\bar{p}$ single-diffractive dissociation process was obtained. We stress that we had no free parameters in this analysis. We hope that this approach will give a reliable predictions for both cross sections of diffraction dissociation to large mass states and particle production in this process at LHC energies and can be used to calculate backgrounds from diffractive processes in experiments where direct observation of diffractive processes will not be possible.

6 Acknowledgements

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